

## BIOLOGICAL AND HEALTH EFFECTS OF ELF ELECTROMAGNETIC FIELD

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**Abstract:** The concern has been raised over the effects of the exposure to ELF-EMF on human health after the publication of Wertheimer in 1979. Since then, many research efforts began to investigate possible association between ELF-EMF exposure and human health risk. This presentation will shortly discuss the biological and health effects to ELF-EMF exposures from the points of human and animal studies and the evaluation on this topic.

**Key words:** Biological Effect, Human Health, Extremely Low Frequency, Electric Field, Magnetic Field

### 1. Introduction

In addition to naturally existing electromagnetic fields, we conduct our daily activities in man-made electromagnetic environment. Electric appliances operating at 50 or 60Hz, which is in the extremely low frequency (ELF) region, are in everyday use while a portion of our activities are conducted under high voltage power lines. The biological and health effects of exposure to extremely low frequency electromagnetic fields (ELF-EMF) produced by electric appliances and facilities have become a subject of concern. During past two decades, the questions of whether the exposure to the man-made ELF-EMF may link to adverse health effects have been raised. After the long-term researches, the several expert committees have reviewed the evidence for a possible association of exposure to ELF magnetic fields with a small increase risk for cancer based on epidemiological research.

### 2. History of the ELF-EMF Problem

In the past, it was assumed that exposure to EMF produced no harmful effects on humans. The report by Soviet researcher at the 1972 CIGRE meeting that the results of studies on workers exposed to high voltage electric fields indicated possible

harmful effects was unsettling. At the same time, the researcher of Johns Hopkins University reported that a 9 year study of ten electrical workers several areas showed that there were no harmful effects.

In 1979, Wertheimer and Leeper compared the distribution of childhood cancer in the Denver area with wire code, the index of degree of current flow of transmission and distribution lines [1]. They inferred that a possible association exists between childhood cancer, childhood leukemia and exposure to magnetic field. In 1982, Milham studied the relationship between cause of death and occupation between 1950 and 1979 [2]. He found that for occupation where opportunities for exposure to EMFs were believed to be high, a high death rate from leukemia was observed. After publication of these reports, many researches on the possibility of a link between residential and occupational exposures to magnetic fields and cancer in human have appeared. In 1992, five-year efforts, EMF RAPID program in U.S were designed to improve the understanding of the potential adverse health effects of ELF-EMFs. For residential study, the topic focuses on leukemia and brain cancer in children, leukemia, brain cancer and breast cancer in adults. The occupational study focuses on mainly leukemia and brain cancer although concerning with suicide, depression, Alzheimer's disease (AD) and amyotrophic lateral sclerosis (ALS). Laboratory studies are divided into two areas, *in vitro* and *in vivo* studies. The approach with *in vitro* studies has been used in an effort to find possible mechanisms for interaction between ELF-EMF exposure and biological system. The *in vivo* studies provide the information on how ELF-EMF interacts with biological system, using the whole organisms such as experimental animals and human. Experimental areas have included nervous system, physiology, reproduction, behavior, immunology, endocrinology, and a range of other areas.

## 4B1-1

### 3. Physical interaction with biological systems

When EMF is considered as particle, photon energy  $E$  (eV) is defined as follows.

$$E = hf = hc/\lambda = (1.24 \times 10^{-6} \text{ eV} \cdot \text{m})/\lambda$$

Here,  $h$  is Planck's constant,  $\lambda$  is the wavelength of the electromagnetic wave,  $f$  is the frequency,  $c$  is the speed of light. Energy is inversely proportion to wavelength and electromagnetic wave exceeding 10eV or wavelength less than 100nm (ultraviolet region) is called ionizing radiation. This can have the ionizing effect of dividing neutral molecules into electrons and positive ions and has the capability to break chemical bonds. At ELF regions, the photon energy is extremely small,  $10^{-13}$  (eV) due to the wavelength (6,000km or 5,000km at 50Hz and 60Hz). ELF-EMFs do not have the energy to break chemical bonds in DNA by ionizing effects. Therefore, it is generally agreed that ELF-EMFs do not have the power to cause heating or ionizing. The effect of ELF-EMF on organism is based on the induction of electric currents. However, there are major differences in the size and direction of the current induced inside organism by ELF-EMFs. In the case of ELF magnetic field, the induced electric current forms closed loop, so-called eddy currents are induced. This eddy current is zero at the center of plane perpendicular to the magnetic field and become larger with distance from the center. This is a basic physical mechanism for interaction of ELF-EMFs with tissues.

### 4. Laboratory Studies

In order to understand the biological and health effects of ELF-EMFs on animals and humans, the attention has focused on cellular proliferation, gene expression, tumor promotion, protein biosynthesis, enzyme activities, chromosomal damage, mutation and neurobiology, et al. Animal models, which, are particularly important, have been used in a variety ways to investigate the whether there is a potential relationship between ELF magnetic field and cancer.

Cancer studies: There are many researches to investigate carcinogenicity of ELF magnetic field. Using of rats and mice, based on the studies of exposures to ELF magnetic fields alone, and in combination with known carcinogens (DMBA), there is no evidence that exposure to ELF magnetic

fields causes cancer in animals. ELF magnetic fields had no effects on the incidence of chemically initiated tumors. As carcinogenesis is recognized as a multistep process, one approach is to assume the ELF-EMF acts either as an initiator or promoter. This initiation/promotion approaches is used to evaluate skin tumor, mammary tumor in rats. IARC judged that there are no data on carcinogenicity to animals of static magnetic fields, of static and ELF electric fields

Melatonin: One of the main issues in research is the melatonin hypothesis. It was proposed that the reductions in nighttime melatonin secretion due to ELF-EMFs lead to the development of cancer. The change of melatonin secretion was first reported by Wilson, who exposed rats to ELF electric fields, 1.7 to 1.9kV/m. This result could not be replicated by other investigations. The effect of ELF magnetic field on melatonin secretion was first noted by Kato et al. Since then, using rats, mice, Djungarian hamsters, sheep and baboon, studies have been carried out. However, the animal studies are inconsistent themselves.

Teratology and development: From studies of rodents, rats and mice exposed to ELF electric and magnetic field during pregnancy or life time, ELF-EMF have no adverse effects on the embryonic or postnatal development.

Neurobehavioral studies: ELF electric field can be detected by animals as surface charge effects of the body. The thresholds for ELF electric field detection in rat is about 5-15kV/m. Detection thresholds are similar in other species including humans. However, detection thresholds for ELF magnetic fields in animals are not clear. Nonhuman primates were used to examine the effects of combined exposure to ELF electric and magnetic fields. This result did not detect effects on operant performance even at 30kV/m and 100  $\mu$  T. Visual perception in the form of magnetophosphenes has been demonstrated in humans.

Immunological and hematological studies: The effects on immune system have been investigated in rats, mice, monkeys and baboons. The studies have evaluated a wide variety of immune function endpoints, cell-and humoral-mediated immunity, immune organ (spleen, thymus), cell, macrophages, natural killer cells, cytokine production antibody synthesis etc. Exposures to ELF electric fields does not appear to affect the immune system. The results

of in vivo and in vitro ELF magnetic field exposures indicate that in the mT range, ELF magnetic field can act as stimulator or inhibitor of cellular activity. On the basis of in vitro studies, in vivo ELF magnetic field exposure seems to act as a physical stressor. Studies have found no significant effects of ELF magnetic fields on the hematological system (erythrocyte, platelets, red blood cells, leukocyte).

In vitro studies: Many experiments have been carried out to study the effects of ELF-EMF on cell in culture. Above about 0.1mT, studies including some replications, have demonstrated effects on ODC activity. Not all replication attempts have succeeded. Many other biological effects have been reported above about 1mT. How ELF magnetic field exposure produces such effects is unknown. For most effects, such as those reported on genotoxicity, intracellular calcium concentrations, or general patterns of gene expression, convincing and reproducible results have not been observed. None of the in vitro effects are necessarily indicative of an adverse health effect. Without knowledge of the mechanisms, effects observed at high field strengths cannot be extrapolated to low fields, because the mechanisms may be different [3].

### 5. Studies in humans

The effects of ELF-EMF exposure on humans come from research efforts in individual laboratories. It includes a series of variety of studies in the 1960s in the former Soviet Union and in Prof. Hauf's laboratory, in Freiburg in the Federal Republic of Germany. Because the first report in 1979 suggested an association between residential ELF magnetic field and childhood leukemia [1], most epidemiologic studies have focused on ELF magnetic field in residence.

Volunteer studies: Human were unable to perceive ELF magnetic fields at levels up to 1.5mT. However, in the form of magnetophosphene, humans experience a visual flickering sensation during exposure to ELF magnetic field above 3-5mT. The threshold is about  $10\text{mA/m}^2$  at 20Hz. In the case of ELF electric fields, human can perceive electric fields greater than 20kV/m as surface charge effects and a small percentage of people can perceive field strengths below 5kV/m.

Effects in children: Based on nine original studies,

pooled-analysis suggests that no excess risk for childhood leukemia from residential exposure to ELF magnetic fields below  $0.4\ \mu\text{T}$ , and for above  $0.4\ \mu\text{T}$  a doubling of the risk of leukemia in children. This is unlikely to be due to chance, but may be affected by selection bias. This evidence is also not strong enough to justify a firm conclusion that ELF magnetic field cause leukemia in children. From the IARC report, no consistent relationship has been seen in studies of childhood brain cancers or cancer at other sites and residential ELF-EMS. However, these studies have generally been smaller and of lower quality [6].

Effects in adults: 1) Residential exposure: Epidemiological data are sparse concerning the relationship between cancer in adults and residential ELF magnetic field exposure. A fairly consistent association between residential exposure and adult leukemia and brain cancer has not been established. For breast and other cancers, the existing data are not adequate to test for an association with exposure to ELF-EMF [6]. Although there have been fewer studies, there is no reason to believe that residential exposure to ELF-EMF is involved in the development of leukemia or brain cancers in adults. 2) Occupational Exposure: epidemiological studies attempted to assess possible associations between the exposure to ELF-EMF and the risk of leukemia, brain and breast cancers among workers. Electrical occupations are utility workers, electrician and railway drivers. The IARC report concludes: studies conducted in the 1980s and early 1990s pointed to a possible increased risk of leukemia, brain cancers and male breast cancer in jobs with presumed exposure to ELF electric and magnetic fields above average levels. The interpretation of studies was difficult mainly due to methodological limitations and lack of appropriate exposure measurements. Also, a bias towards publication of positive findings could not be excluded [6].

### 6. Evaluations

Several expert groups have reviewed the possible health hazards from the results of biological and human studies of exposure to ELF EMFs.

In 1997, National Research Council noted that wire codes are associated with an approximate 1.5-fold excess of childhood leukemia based on an analysis of the epidemiologic literature, but

## 4B1-1

concluded; based on a comprehensive evaluation of published reports relating to the effects of ELF electric and magnetic fields on cell, tissues, and organisms (including humans), the current body of evidence does not show that exposure to these fields presents a human health hazard [4].

In 1998, the NIEHS Working Group Report concluded: classification of ELF EMF as possibly carcinogenic (Group 2B) is a conservative, public-health decision based on limited evidence of an increase risk for childhood leukemia with residential exposure and an increase occurrence of chronic lymphocytic leukemia associated with occupational exposure. For these particular cancers, the results of in vivo, in vitro, and mechanistic studies do not confirm or refute the findings of the epidemiological studies. The overall body of evidence has, however, laid a foundation for furthering our understanding of the biological effects, mechanisms, and exposure circumstances that may be related to the possible carcinogenicity and other adverse human health effects of exposure to ELF EMFs [5].

Following these evaluations, an expert scientific working group of International Agency for Research on Cancer (IARC) evaluated in 2001: *ELF magnetic field is possibly carcinogenic to humans (Group 2B)*, based on consistent statistical associations of high level residential ELF magnetic field with a doubling of risk of childhood leukemia. Children who are exposed to residential ELF magnetic field less than  $0.4 \mu\text{T}$  have no increased risk for leukemia. Because of insufficient data, *static magnetic field, static and ELF electric fields were evaluated as not classifiable as to their carcinogenicity to humans (Group 3)*. Studies in experimental animals have not shown consistent carcinogenic or co-carcinogenic effects of exposures to ELF magnetic field, and no scientific explanation has been established for the observed association of increased childhood leukemia risk with increasing residential ELF magnetic field exposure [6].

Although IARC concluded that ELF magnetic field is possibly carcinogenic to humans, it remains that there are other explanations for the observed association exposure to ELF magnetic field and childhood leukemia.

## 7. Conclusions

Now, the International EMF Project organized by WHO is just underway to assess health and environmental effects of exposure to EMF including static (DC), ELF (>0-300Hz), IF (>300Hz-10MHz) and radio frequency(10MHz-300GHz). This Project is scheduled to complete health risk assessment of EMF in 2007 and the goal is to publish EHC Monographs.

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